Sensory Information Systems Program

6 March 2012

Willard Larkin
Program Manager
AFOSR/RSL
Air Force Research Laboratory

Integrity ★ Service ★ Excellence

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **06 MAR 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Sensory Information Systems Program**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Office of Scientific Research (AFOSR/RSL),Air Force Research Laboratory,875 North Randolph Street Suite 325,Arlington,VA,22203-1768**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the Air Force Office of Scientific Research (AFOSR) Spring Review, Arlington, VA, 5-9 March, 2012.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**36**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

PORTFOLIO OVERVIEW

Program manager: Willard Larkin

BRIEF DESCRIPTION OF PORTFOLIO:

- **Auditory modeling for acoustic analysis**
- **Biological polarization optics & vision**
- **Sensori-motor control of bio- flight & navigation**

SUB-AREAS IN PORTFOLIO:

Sensory Information Systems (3003/L)

Program Trends and Strategy:
TOPIC AREA OVERVIEW

Advanced Auditory Modeling:

40%

Scientific Question: How does the auditory brain parse acoustic landscapes, bind sensory inputs, adapt its filters, hear through noise and distortion? Could autonomous listening devices emulate neurology to match or exceed human auditory analysis, e.g., to detect and identify speech targets in noise and reverberation?

Polarization Vision & Optics:

12%

Scientific Question: How do natural photoreceptors detect and how do animal brains interpret polarization information? How is it used for nocturnal navigation or recognition of obscured targets? Can these unique bio-optical systems be emulated?

Sensorimotor Control of Flight & Navigation:

47%

AFOSR BioNavigation Research Initiative

Scientific Question: How does neural control make natural, low-Reynolds No. flight autonomous, efficient, and robust? Discover principles of multisensory fusion, distributed sensors and actuators. Develop control laws for emulation in MAVs.

Strategy: Forge useful connections between math and biology

Grantees' Self-Organized Research Workshops (2011)

Neural Oscillations and Speech Perception.
24 May. Hosted by NYU.

Science & Applications for Bio-Inspired Navigation and Control.
23-25 May. Hosted by AFRL/RW.

Bio-Optics and Photoreception.
27-30 June. Hosted by U. Bristol.
Funded by the Rank Prize Foundation

Encoding for Auditory Representations.
22-23 August. Hosted by U. Washington.

Informational Masking & Binaural Hearing.
17-19 Nov. Hosted by Boston U.

Brain Rhythms and Cortical Computation.
18 Nov. Hosted by NYU.

Convened by grantees; No AFOSR workshop funding

Sensory Information Systems Program

Primary Coordination

NSF
B. Tuller

ONR
T. McKenna
M.Steinberg

ARO
E. Schmeisser

AFRL/RI
A. Noga

AFRL/RH
D. Luginbuhl
N. Iyer

AFRL/MN
R. Wehling

WRAMC
D. Brungart

Sensory Information Systems Program -- People

Dr. Jennifer Talley,
Biology

Dr. Talley (Ph.D. 2010) was recruited from AFOSR-sponsored project at Case Western U. to insect flight lab at AFRL/Eglin

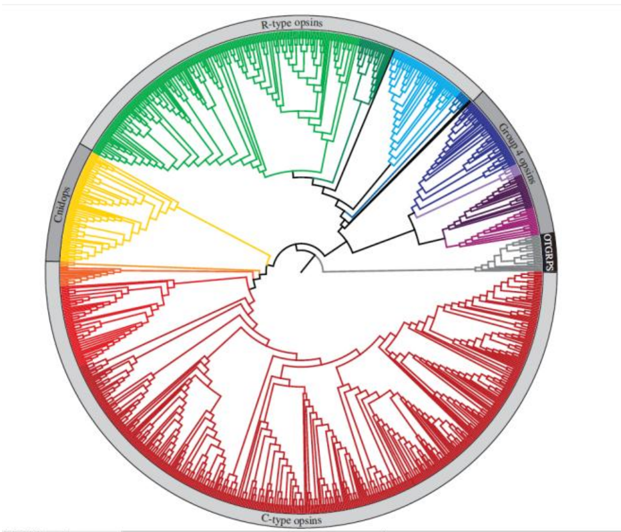
2012
Judith A. Resnik Medal
Dr. Pramod Varshney,
Syracuse U.

Dr. Eric Thompson,
Acoustics

Dr. Thompson (Ph.D. 2009) was recruited from AFOSR-sponsored projects at Boston Univ. to psychoacoustics lab at AFRL/RH

RECENT HIGHLIGHTS

OPSIN MAP



New Genomic Analysis reveals maximum-likelihood phylogenetic model for Photoreceptor Opsins


PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

ISSN 0962-8436
volume 366
number 1565
pages 611–782

New directions in biological research on polarized light

Papers of a Theme issue compiled and edited by Justin Marshall, Thomas W. Cronin and Martin F. Wehling

The world's first science journal

Royal Society Publishing

12 March 2011

AFOSR Polarization Biology Sub-program featured in J. Royal Society Special Issue

DR. KEY DISMUKES

WRIGHT STATE UNIVERSITY

Keynote Speaker for AFRL – Wright State Internat. Symposium on Aviation Psychology

Recent Transitions

TO: **Navy**: Bio-inspired method to classify acoustic sources, e.g., vehicles, humans, marine animals etc., using cortical auditory model. Dr. Sam Pascarelle, Advanced Acoustic Concepts, Inc.

TO: **AFRL-- Eglin**: Measurements and data on biological wide-field-of-view optical systems to enable 6.2 and 6.3 efforts in vision-based guidance and navigation. D. Stavenga, U. Groningen, N. Strausfeld, U. Arizona, M. Wehling, et al.

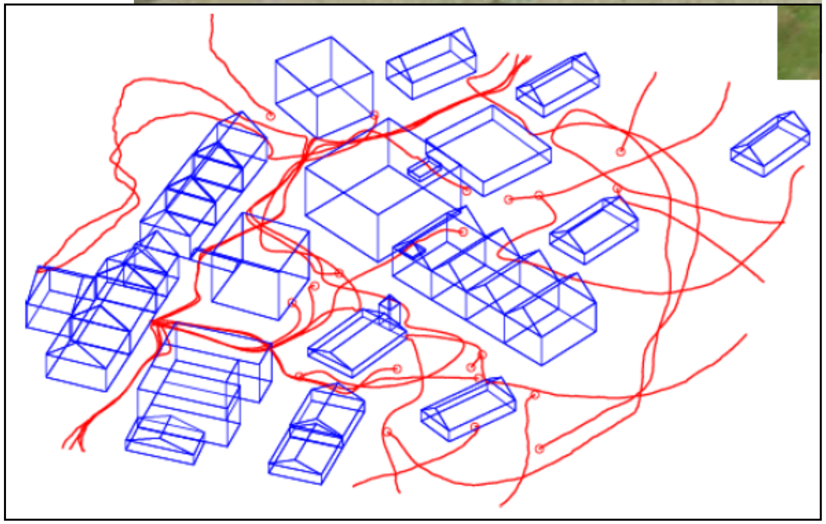
TO: **Bloedel Hearing Institute**: New, patented method to improve auditory coding in cochlear implants. Developed by Dr. Les Atlas, U. Wash. Dr. Jay Rebenstein will develop commercial applications.

TO: **AFIT**: Techniques in electrophysiology and neuroanatomy for mechanical engineering projects to emulate flapping wing flight. Dr. Mark Willis, Case Western U., Dr. Anthony Palazotto, AFIT

TO: **DARPA**: System for adaptive, autonomous control of robotic movement, based upon hierarchical neural model of biological control. Roger Quinn &. Roy Ritzmann, Case West. U.; G. Pratt, DARPA.

Autonomous Steering:
Transition to Army MAST

Quadrotor implements autonomous 3D navigation using wide field-of-view optic flow



Inspiration:

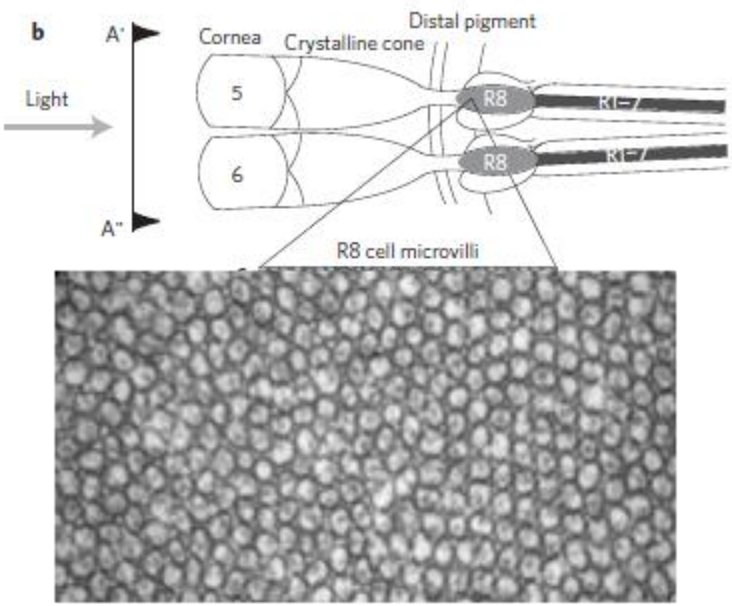
- Insect Compound Eye Research
  Eglin AFB 6.1 (M. Wehling, et al.)
- Insect Visual Target Detection Modeling
  Tanner Research (P. Shoemaker.)
  U. Adelaide (D. O'Carroll)
- Insect Flight Behavior Modeling
  U. MD. (J. S. Humbert)

Microautonomous Systems and Technology
http://www.avl.umd.edu/

Bio-Emulation Progress
From 6.1 at U. Queensland, U. Bristol, & UMBC

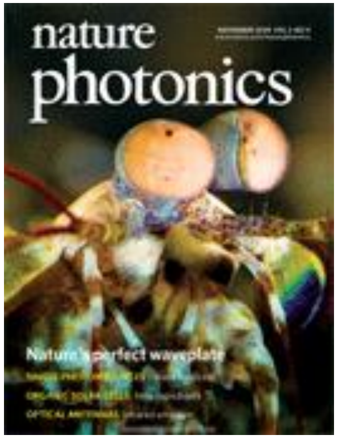
1. Discovery:

Polarization photoreceptor imparts λ-invariant 90^{o} phase delay



Honeycomb structure of photoreceptor's optical retarder membrane

2. Optical Modeling:

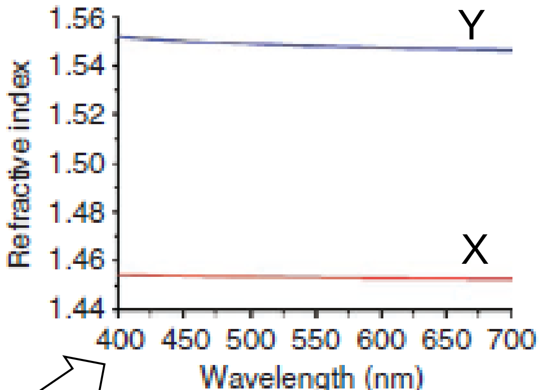


"Nature's Perfect Waveplate"

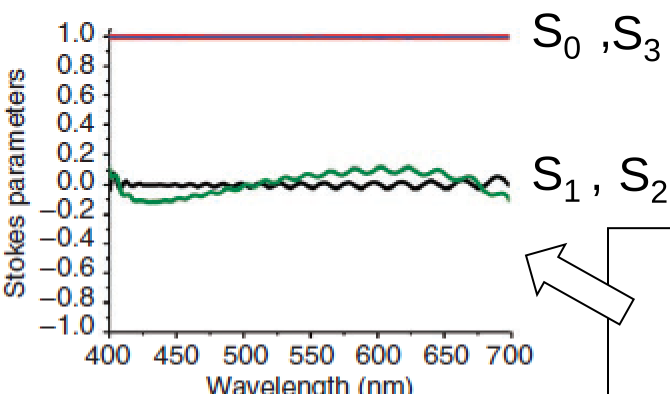
Key property:
Intrinsic birefringence of microvilli elements, in balance with form birefringence, yields wavelength-invariant phase delay.

3. Emulation

Nano-Rod Deposition Recipe Emulates Biological Achromatic Phase Retarder

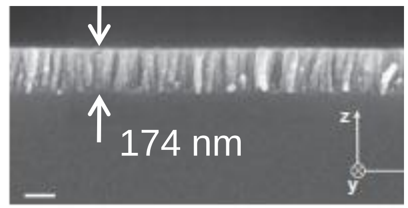


Nano-rod array exhibits birefringence

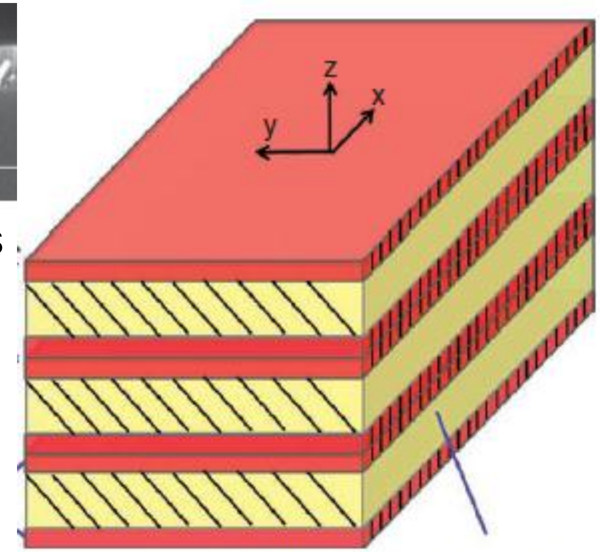


All 4 Stokes parameters remain nearly constant in a multi-layer structure

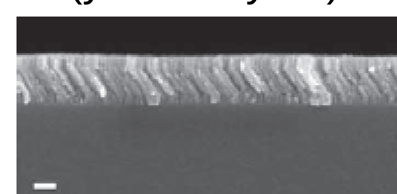
Deposition Angles Alternate in Ta_2O_5 Nano-rod Layers



Upright nanorods (red layers)



Tilted nanorods (yellow layers)



Yi-Jun Jen, Nature Comm. 21 June 2011

Auditory Modeling for Acoustic Analysis – Extramural Grants

- **L. Atlas** (U. Washington):
  New approach to modulation representation and filtering.
- **E. Bleszynski** (Monopole Research):
  Math model of bone- & tissue-conducted sound
- **M. Elhilali** (Johns Hopkins U.):
  Cortical model for acoustic scene segregation
- **O. Ghitza** (Boston U.):
  Theory of speech parsing via brain rhythms
- **W. Hartmann** (Mich. State U.):
  Sound localization
- **G. Kidd** (Boston U.):
  Informational masking & speech segregation
- **R. Kumaresan & P. Cariani** (U. Rhode Is. & Harvard):
  Spectro-temporal codes for auditory signal representation
- **D. Wang** (Ohio State U.):
  Computational auditory scene analysis

Mathematical and Psychoacoustic Research to Understand & Emulate the Human Listener's Auditory Capabilities and to Enhance these Capabilities where Possible.

4 NEW TECHNICAL ADVANCES

Pointillistic Speech Coding

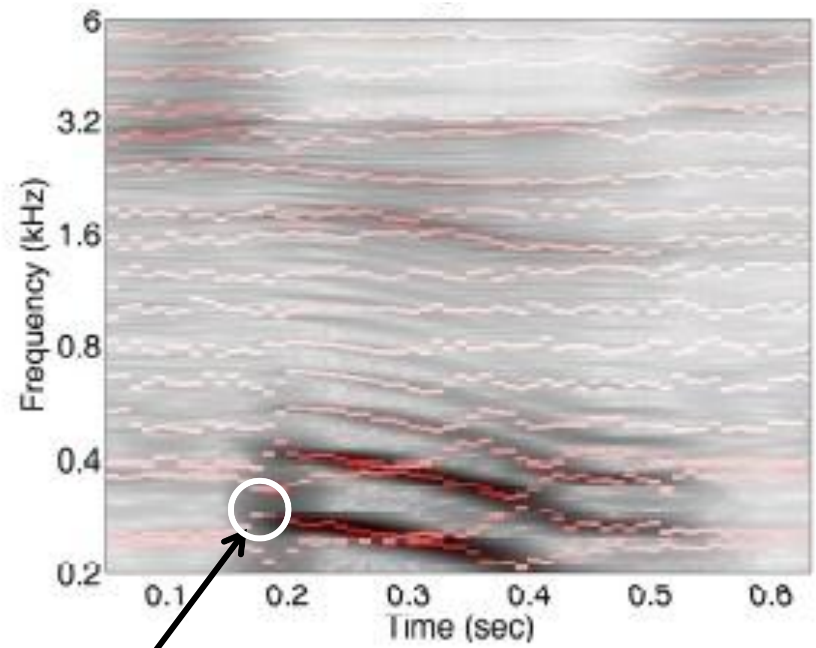
G. Kidd, Boston Univ., 2011

New Technique Isolates Informational & Energetic Masking

Background:

- What listeners can hear in real, multisource acoustic environments is more constrained by informational masking, than by direct, energetic interference of one sound by another.
- AFOSR seeks techniques to study & suppress informational masking.
- Sparse pointillistic coding leaves speech remarkably intelligible, eliminates energy overlaps, isolates effects of informational "cross-talk."
- Briefed to AFRL/RI in Dec. 2011.

A sparse, pointillistic rendition of the word "SHOES," overlaid on the conventional spectrogram



Each time/frequency slice of speech has been replaced with a matching cosine fragment.

Red color scales the intensity.

Transaural Synthesis: A New Technical Advance in Auditory Measurement

W. Hartmann, MSU.

Scientific Challenge:

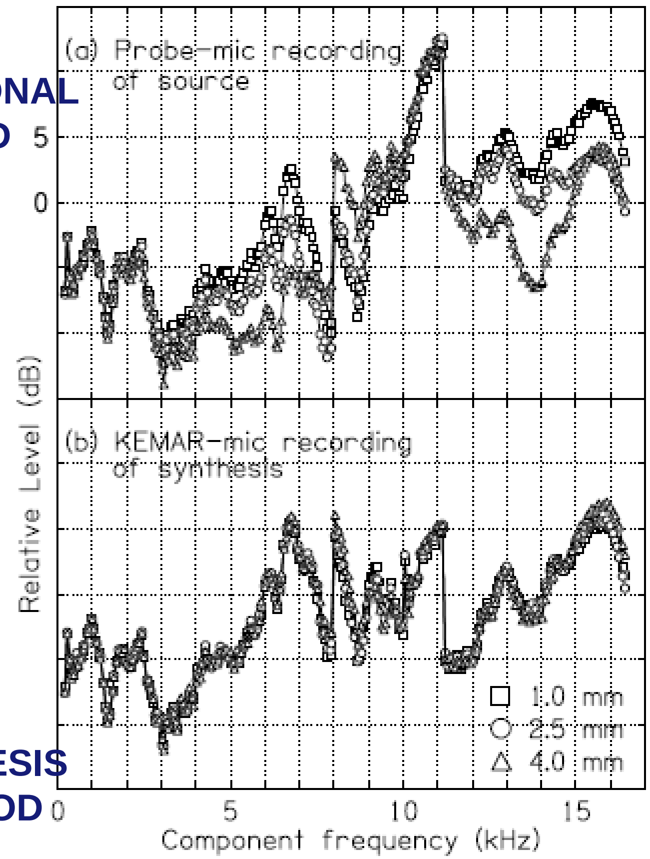
How does binaural hearing disclose the locus of sound in real 3D environments?

Transaural Synthesis Method:

- Eliminates inter-aural crosstalk, compares localization judgments with precisely known acoustic parameters in the ear canals.
- Tests auditory theory by manipulating Interaural phase and amplitude, comparing real sounds with “virtual” sounds.
- Tests in real rooms & environments, with varied reverberation – no headphones.
- Self-compensates for probe-tube positions, enables precise reproducability.

NOISE SPECTRUM MEASUREMENTS IN EAR CANAL

CONVENTIONAL METHOD



SYNTHESIS METHOD

Acoustic Source Separation:

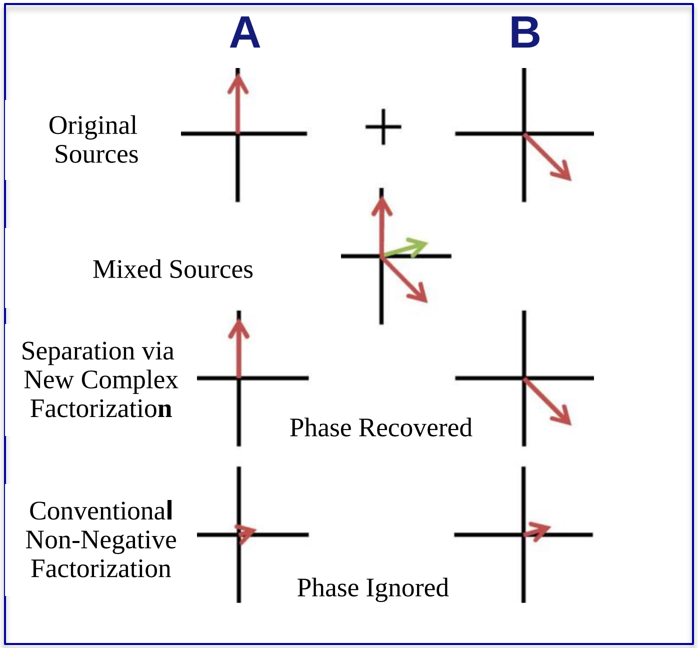
Recovering Multiple Speech Signals from a Single Channel

Research Challenge:

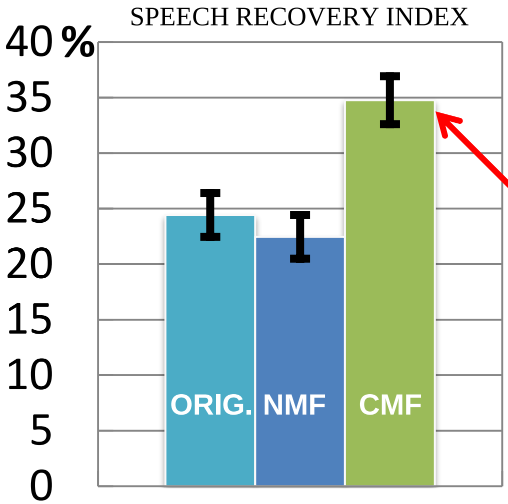
Devise a factorization method to:

- Recover both magnitude and phase for each speech component superimposed in a single channel
- Avoid trial-and-error basis selection.

Why Phase Matters:



Brian King
U. Washington
Ph.D. Candidate
&
RH Summer Student



New Complex Matrix Factorization method solves superposition and phase problems, eliminates ad hoc basis selection, & Improves speech recognition scores

King & Atlas, IEEE Trans on Audio, Speech and Language Processing (Nov. 2011)

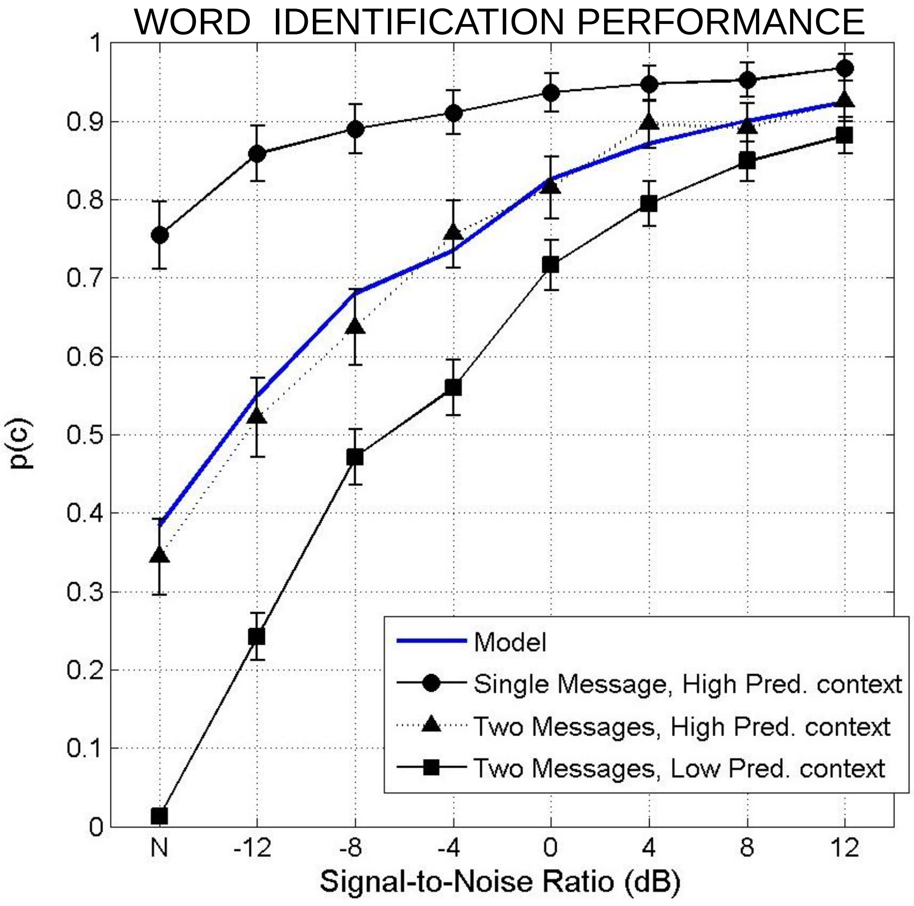
How do Human Listeners Sort Overlapping Speech Information ?

Scientific Question:

When each ear receives a distinct message, can the auditory brain extract key information from both?

Surprising Result:

Manipulation of word predictability in dichotic listening strongly supports a model of attention-switching, rejects hypothesis of divided attention.



(Level of noise masking a keyword)

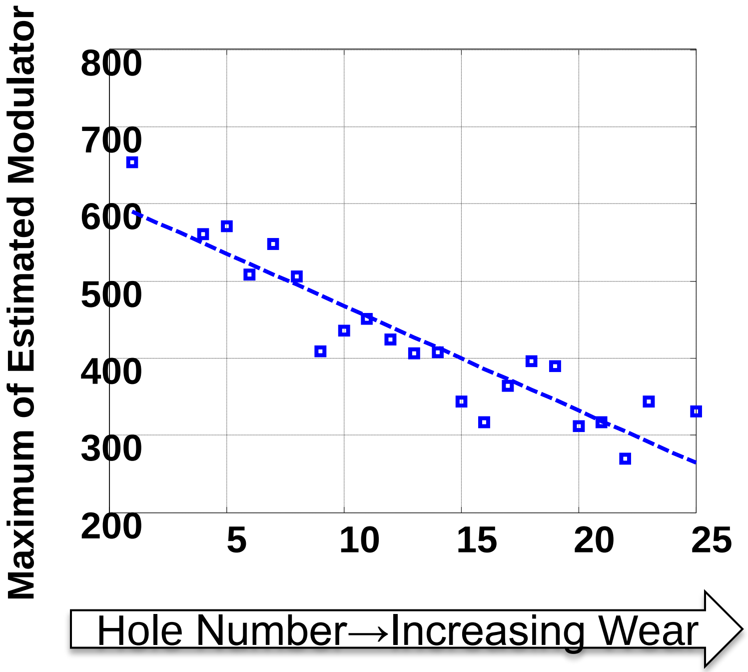
N. Iyer, B. Simpson, Principal Investigators, 711 th HPW/AFRL/RHCB Battlespace Acoustics

Coherent Modulation Analysis:

Dr. Les Atlas, University of Washington

Mathematical challenge:

Estimate and separate the linear time-invariant and frequency-invariant components of an acoustic source.



Approach:

Theory of Complex Modulation Filtering, devised by Prof. Les Atlas (originally for analysis of speech signals.)

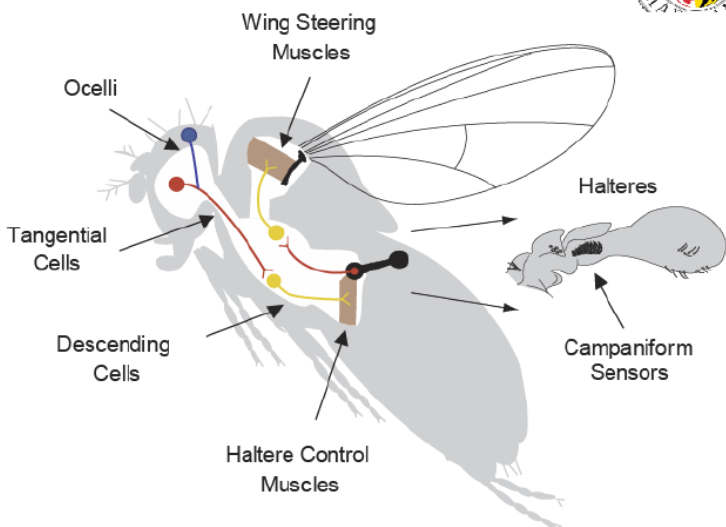
Unexpected Application:

A simple, one-microphone set-up detects hole quality while drilling in airframe composite material.

Sensori-motor Control of Natural Flight and Navigation

Fundamental Question:

What underlying principles drive biology's design of actuation and sensing architectures?



Motivating Observations from Insect Research :

- Sensors are "noisy," redundant, distributed in non-orthogonal coordinates.
- Inputs fuse across modalities prior to activating flight muscles.
- No conventional distinctions between estimate/control or inner/outer loop
- Sensors differ radically in bandwidth & temporal response, e.g., vision lags mechanoreception.

Insect Lab, Eglin AFB
Dr. Jennifer Talley

Sensori-motor Control of Natural Flight and Navigation

▲ = AFOSR BIO-NAVIGATION FUNDING INITIATIVE

▲ **T. Daniel (U. Washington):**
Wing mechanosensor functions.

J. Evers (AFRL/RW):
Natural 3D flight dynamics

M. Frye (UCLA):
Higher-order motion detection

S. Humbert (U. Maryland):
Modeling sensorimotor control

H. Krapp (Imp. College London):
Neural basis of visual steering

P. Krishnaprasad (U. MD):
Modeling formation flight control

▲ **S. Reppert (U. Mass):**
Clock-compensated navigation

R. Ritzmann (Case Western):
Adaptive locomotion control

R. Olberg (Union College):
Dragonfly flight to target capture

S. Sane (Tata Institute):
Insect multisensory integration

P. Shoemaker (Tanner Res.):
Visual detection of small targets

▲ **S. Sterbing (U. MD):**
Wing sensors in bat flight control

G. Taylor (Oxford):
Raptor pursuit strategies in 3D

▲ **E. Warrant (Lund U.):**
Nocturnal navigation

M. Wehling (AFRL/RW):
Neural analysis of optic flow.

▲ **M. Willis (Case Western):**
Visual / olfactory target tracking

International and 6.2 Coordination

U.K.

G. Taylor

H. Krapp

J. Niven

AFRL-DSTL Working Group
Biologically-Motivated Micro-Air-Vehicles

"STATE OF THE ART REVIEW"
Georgia Tech
15-18 June, 2010

Organizers: M. Wehling, AFRL. P. Biggins, Dstl

30 Participants from UK, US, Industry, Academia, & Gov.

Presentations:
https://livelink.ebs.afrl.af.mil/livelink/llisapi.dll?func=ll&objId=24091294&objAction=browse&viewType=1

U.S.

M. Willis

S. Humbert

T. Daniel

Span of Natural Flier Research:
A Few Program Participants

Vertebrates

Hawks & Falcons

Echolocating Bats

Invertebrates

Megalopta genalis
(Nocturnal Bee)

Bombus terrestris

Dragonfly

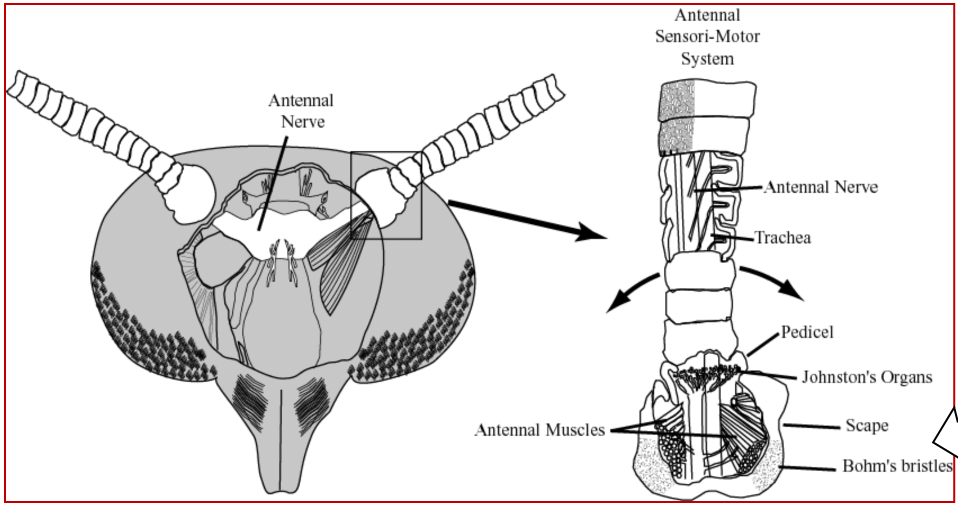
Hawkmoth

Antennae in Flight Control

Dr. Sanjay Sane, Tata Institute, Bangalore, India

Hawkmoth, *Daphnis nerii*

1. Precise control of antennae position is critical for aerial flight maneuvers
2. Control system is closed-loop, with sensory latency of 15 msec.
3. Antennae integrate mechanosensory & photoreceptor inputs



4. Antennae position in flight is governed by Bohm's bristles only at pedicel.

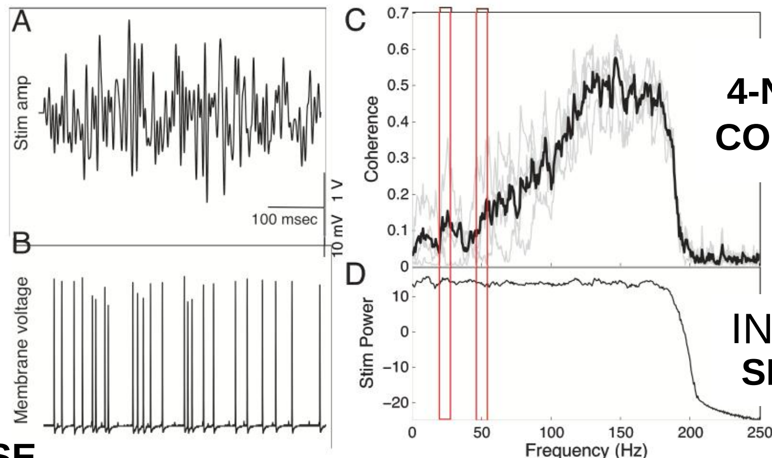
AOARD grant via T. Erstfeld

Wings are Sensory Receptors

- - - A New Research Effort

MECHANICAL INPUT

CORIOLIS REGIONS



4-NEURON COHERENCE

INPUT **POWER SPECTRUM**

NEURON RESPONSE

Wing Campaniform Neurons Respond to Mechanical Forces

Hawkmoth, *Manduca sexta*

Hypothesis:

Wings not only drive flight, but also detect inertial moments.
- - - strain receptors modulate wing shape and position.

T. Daniel (biology) and K. Morgensen (Aeronautics) U. Washington.

The Mode Sensing Hypothesis for Biological Flight Control

Proposed by 3 AFOSR scientists:

S. Humbert

MARYLAND

H. Krapp

IMPERIAL COLLEGE LONDON

G. Taylor

OXFORD

H.G. Krapp, G. K. Taylor, and J.S Humbert (in press) "The Mode-Sensing Hypothesis: Matching Sensors, Actuators and Flight Dynamics."

Theory:

Biological sensors and actuators compose a suite of "matched filters," tuned to salient patterns ("modes") of self-motion – organized to combine multiple inputs into actuation signals encoded in modal coordinates.

Challenge from AFOSR:

- **Test the theory in neurobiology and flight behavior**
- **Devise mathematical emulation suitable for MAVs**

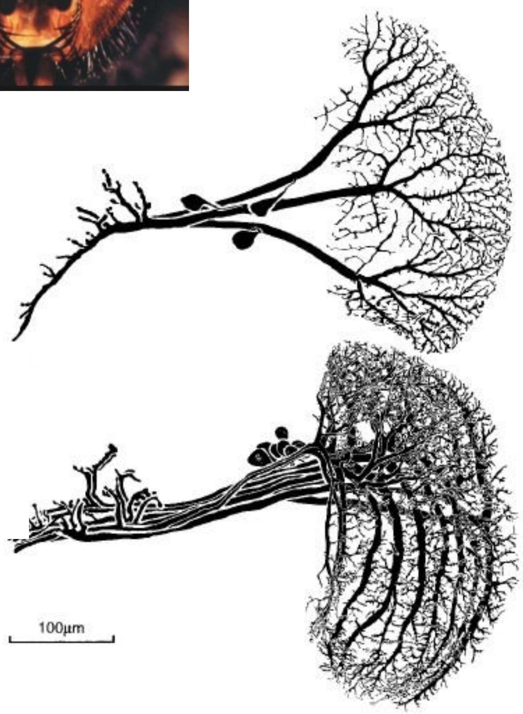
Each Visual System Cell is Tuned to a Preferred Axis of Rotation

Calliphora vicina

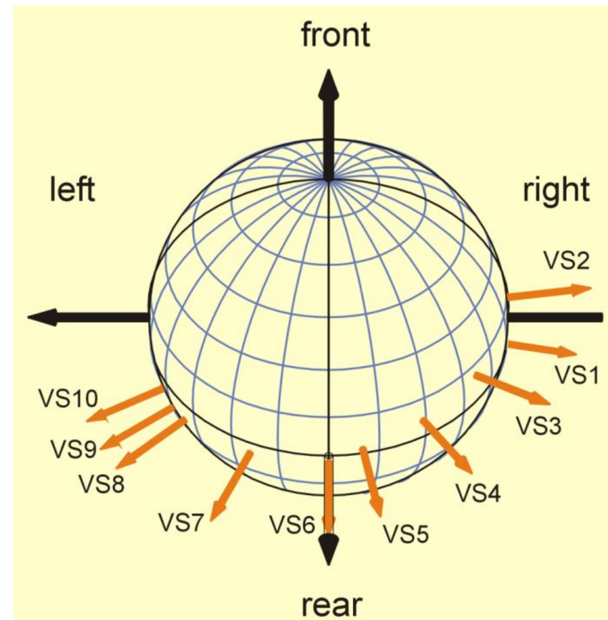
Lobular Plate Tangential Cells (Compound Eye System)

3 HS cells

10 VS cells



10 Vertical System Cells

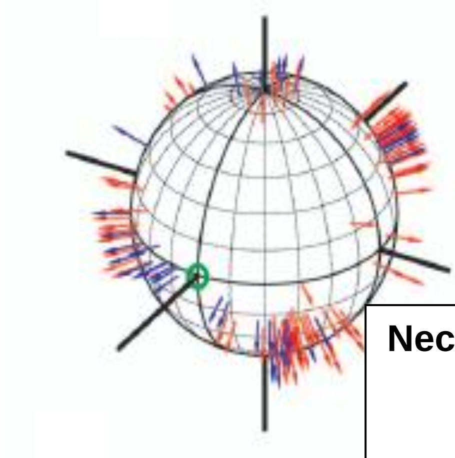


- **Sensory Integration begins by selectively merging these inputs.**
- **The resulting "matched filters" for self-motion are robust and innate.**

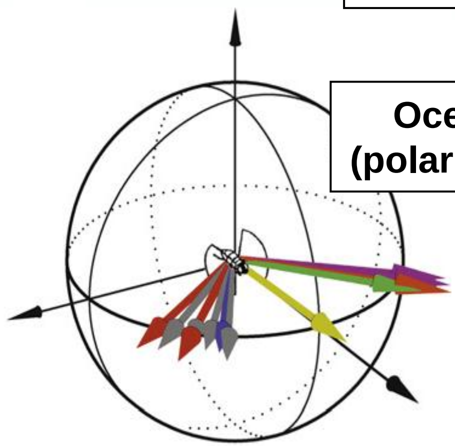
H. Krapp, Imperial College, London

Other Motion Sensor Tuning Differs from Compound Eye Tuning

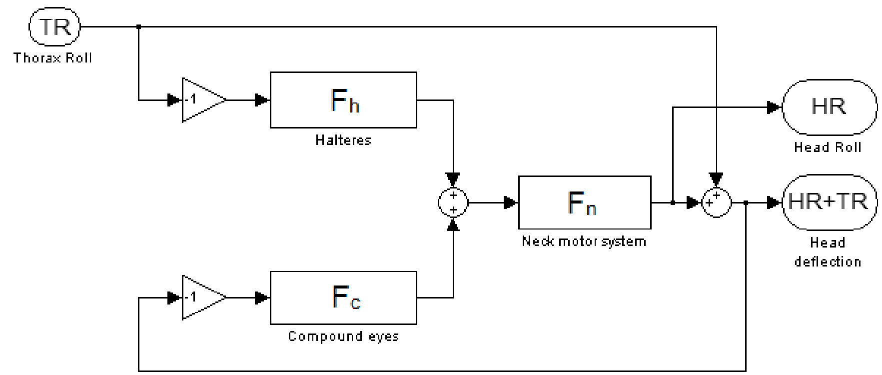
Plots derived from single-unit recordings during controlled rotational stimulation



Neck motor neurons (red)
LPTCs (blue)



Ocellar system (polarization vision)



Theory:
- Short-latency mechanosensors first detect body rotation, then feed forward to induce compensatory head roll via neck motor system …
- Long-latency visual system acts on residual optic flow feedback from incomplete mechanical compensation.
- Behavioral data fit preliminary model for multimodal sensory integration.

Data from U. Cambridge, (M. Parsons) & Imperial College, London (H. Krapp)

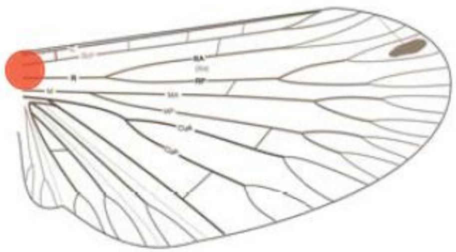
Wing Sensorimotor Activation

- - A New Program Initiative

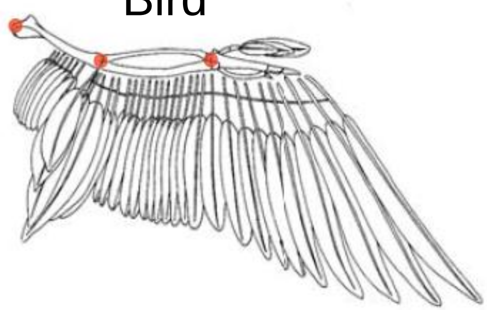
Natural Fliers' Wing Joints

(●) with potential to be controlled during flight

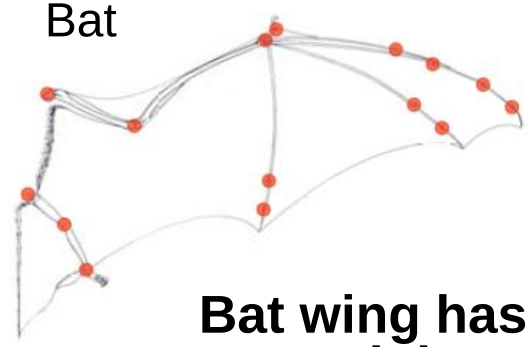
Insect



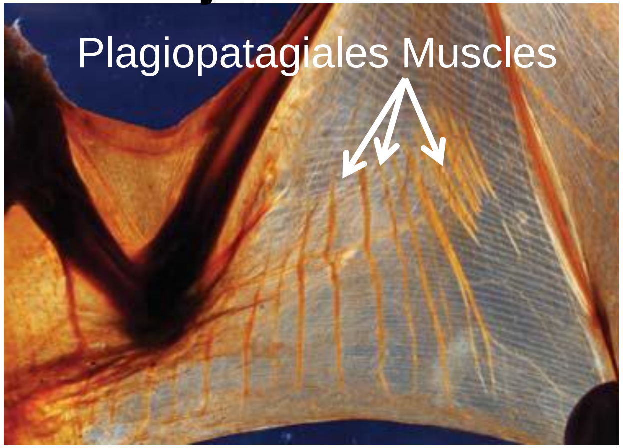
Bird



Bat



Bat wing has Intrinsic, non-joint muscles



Research Questions:

- Discover joint coordination timing
- Determine functional redundancy
- Do joint muscles control force or position?
- Discover what the intrinsic muscles do.

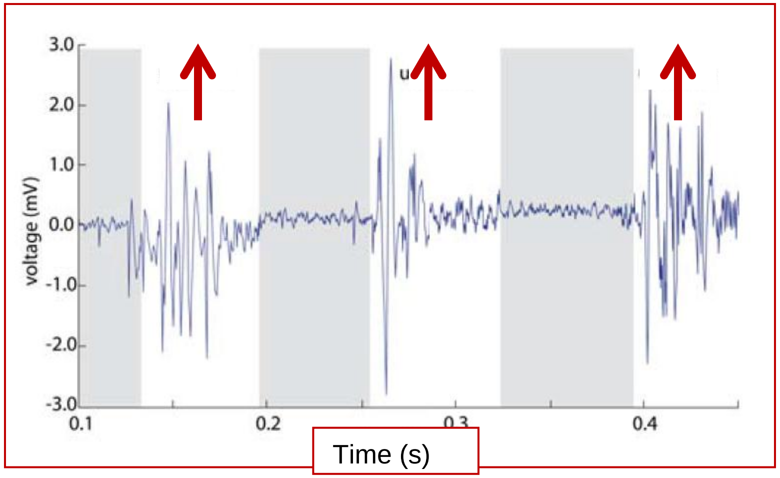
Discovering Bat Wing Musculature Dynamics during Flight

Large bat (1.2kg) in low speed flight has precise control via wing skeletal muscles and wing intramembranous (intrinsic) muscles

ResearchTechniques:

- Electromyography during flight
- Thermal videography for metabolic load)
- Selective, reversible muscle paralysis
- 3D X-ray mapping of skeletal motion

Intrinsic Muscles Active only During Wing Upstroke:

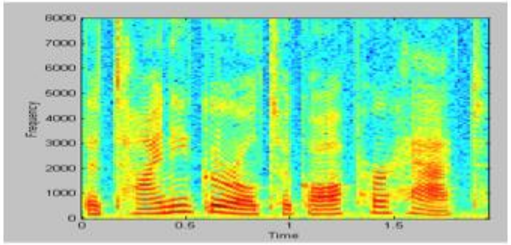


… A Discovery from AFOSR MURI

SUMMARY:
Transformational Impacts & Opportunities

Hearing protection:

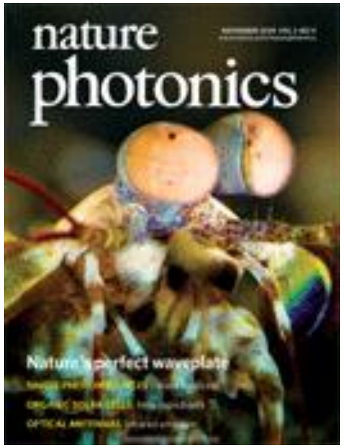
- Massive improvements in high-noise attenuation.



Advanced auditory modeling:

- Mathematics for coherent modulation analysis
- Neural-Inspired analyses to parse acoustic scenes

Optical processing:



- Polarization vision and signaling adapted from biology
- Achromatic 1/4 wave optical retarders
- Emulating compound eye in new optical devices

Autonomous flight control:

- Adaptive airfoils based upon bio-sensory mechanisms
- Steering based upon neural autonomous systems
- Discover sensorimotor basis of formation flight

Questions?

Thank you for your attention.

Willard Larkin, Program Manager, AFOSR/NL
703-696-7793

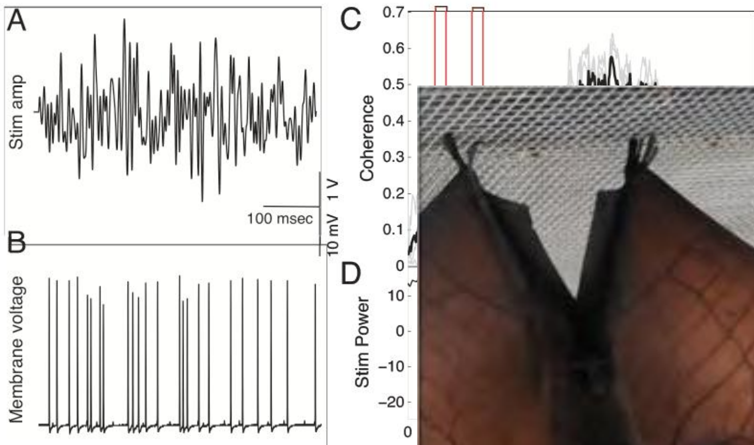
Willard.Larkin@afosr.af.mil

Questions?

Thank you for your attention.

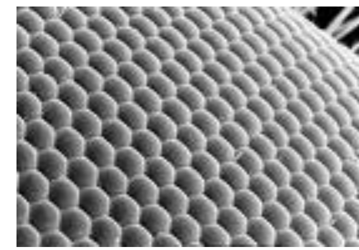
Willard Larkin, Program Manager, AFOSR/NL
703-696-7793

Willard.Larkin@afosr.af.mil


A
Stim amp
100 msec
10 mV
1 V
B
Membrane voltage
C
Coherence
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
D
Stim Power
10
0
−10
−20
0

Robber Fly

No Ocelli
Halteres
No VS cells
5-18 HS cells



New Lab for Insect Vision
Spectral & Polarization
Electroretinography
AFRL/RWG PI: Martin Wehling

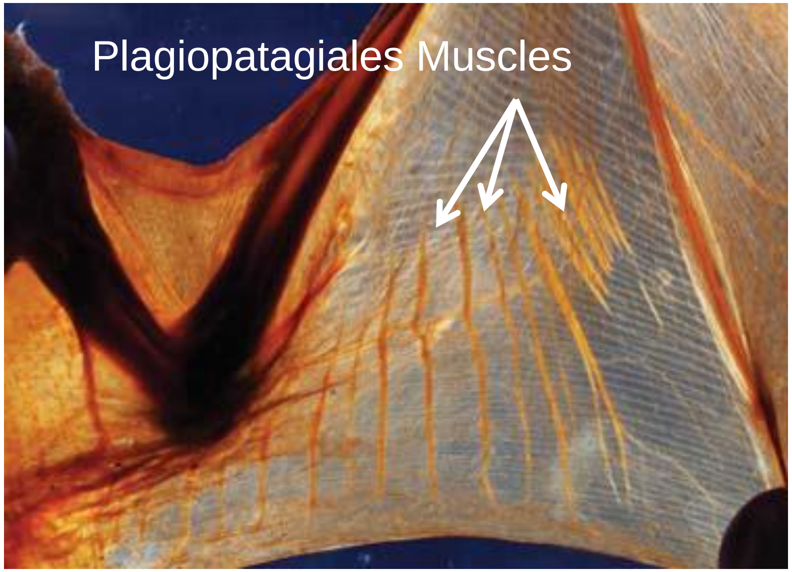
Dynamics of Bat Wing Musculature

S. Swartz, T. Roberts, Brown Univ., 2011

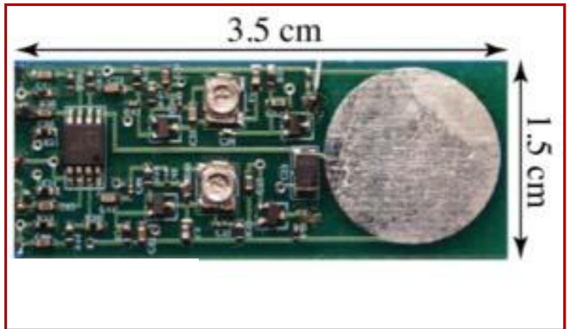
Large bat (1.2kg) in low speed flight maintains precise control via wing skeletal muscles and wing intramembranous muscles

Techniques:

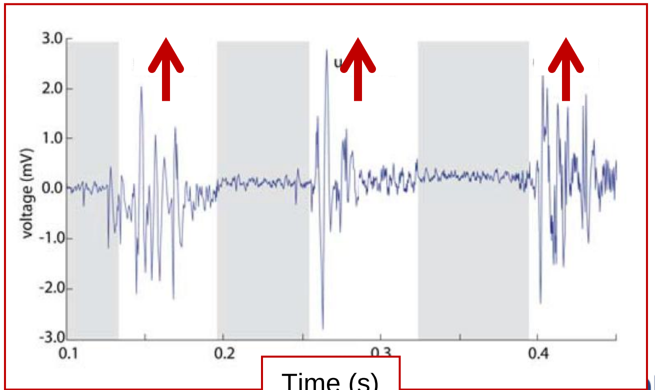
Electromyography during flight
Thermal videography (to measure metabolic load)
Selective, reversible muscle paralysis
3D X-ray mapping of skeletal motion

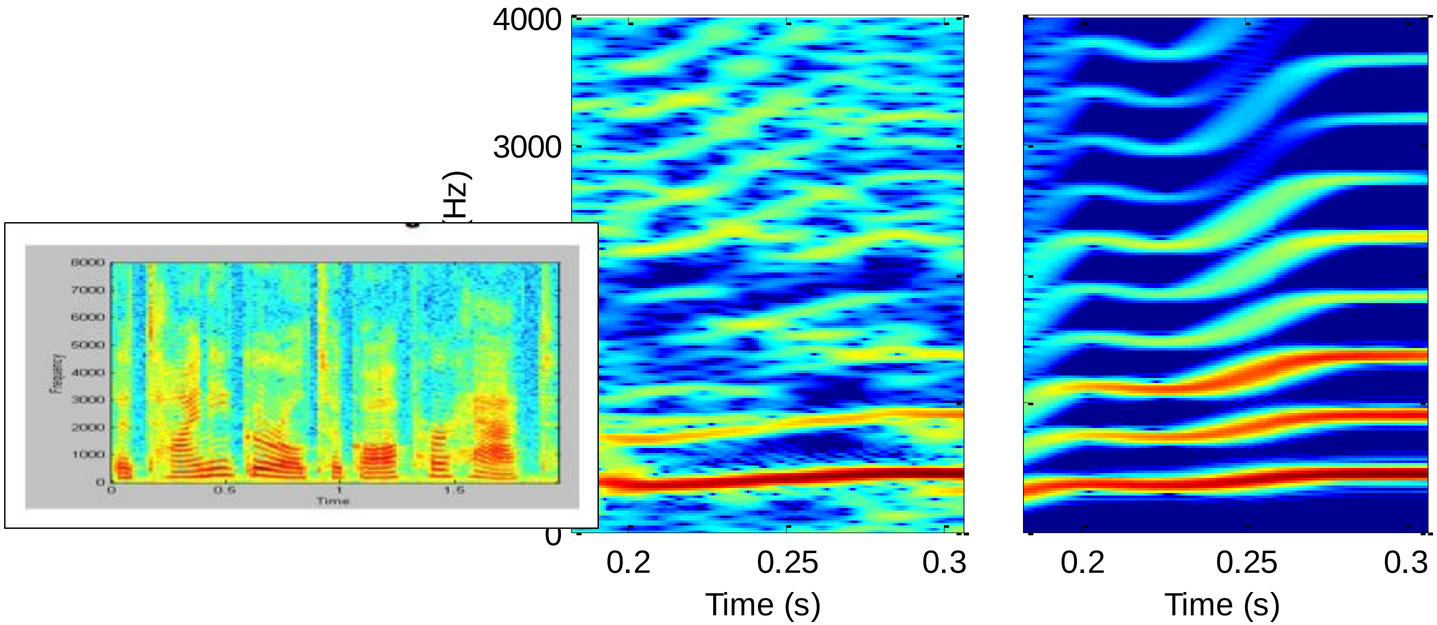


Muscles active during upstroke:



1.5 gm EMG Telemetry
for in-flight muscle activity




4000
3000
(Hz)
0
0.2
0.25
0.3
Time (s)
0.2
0.25
0.3
Time (s)
8000
7000
6000
5000
4000
3000
2000
1000
0
Frequency
0
0.5
1
1.5
Time